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Illustrated Through Physics. 1922

HOW TO STUDY

ILLUSTRATED THROUGH PHYSICS

By

FERNANDO SANFORD

How to Study Series

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INTRODUCTION

Nearly everywhere the principal emphasis in instruction is on knowledge. Tests or examinations on knowledge are the basis of ratings and promotions, and therefore the goal both of private study and of class work. While method is a frequent subject of discussion, it is the method rather of the teacher than of the learner, and even it is judged by the extent to which it leads to acquisition of knowledge. The fact that young people have a method of their own, that its quality is of vital importance, and that it needs great improvement is generally overlooked; for it is unrelated to tests.

A very different conception of teaching is represented in this monograph. Physical Science is shown to owe its progress to improvement in the method of studying it; and as a result of such improvement a single day now brings a greater advance in knowledge of the physical world than did the first thousand years of the Christian era.

Since method has been the secret of the marvelous progress, the principal object of instruction in Physics should not be merely the

comprehension of a lot of facts or even laws, but rather the control of the method of investigation that has proved so fruitful in the discovery of those facts and laws. Furthermore, Physics should be primarily a study of scientific method, because skill in that method has a much broader application than knowledge of subject matter in that field.

The implications for general Education in this point of view are far-reaching. If the idea is sound, the principal object of instruction in some or possibly all other subjects might well be greatly modified, and the method of the learner might be brought into prominence. And since Physics offers the most nearly perfect example of the scientific method, it might be taken as the standard for the other subjects; they differ from it rather in degree than in kind.

How sound are such implications? Certainly modern Education is moving toward this point of view. For illustration, during the last few years the pupil's method of reading has been extensively studied by educational specialists and in many schools improvement in that method has already become a prominent purpose in the teaching of Reading. The method of the learner is slowly receiving recognition.

There are several reasons. The child's enjoy-

ment of school is very dependent upon his skill in study; so also is his real digestion of any subject studied. But even more important is the thought that method in any given field, just as in Physics, has a far wider application to life's problems than subject matter; that control of method is largely the same as mental discipline, or power. In consequence, students should be examined and rated at least as much on their method of procedure as upon their knowledge of subject matter.

Thus there are large possibilities suggested in these pages. But one should understand that movement toward realization of these possibilities must be very slow. The demand is that one shall learn to think, independently and skilfully, in each field studied. That is not only a radical, it is a revolutionary demand; for thinking is a very different thing from acquisition of knowledge. Many curricula and textbooks of the present time fail even to meet the conditions that allow good thinking; they must be made over before a good start can be made toward thinking. Also, since the pupil or student is the one that is to be taught to think—to propose the questions as well as to find their answers—teachers must learn to keep still in the classroom much more than at present, while, at the same time, stimu-

lating activity. In short, since emphasis on method of study requires subordination of both subject matter and teacher to the learner, a radical change in the teacher's point of view, in the very purposes of instruction, is involved. At present not one teacher in one hundred would dare attempt to give demonstration lessons showing how to do "good thinking" in the lessons assigned; and a great majority of teachers could not now show the difference between memorizing a text and good thinking.

It will be a long time, therefore, before the various studies in school and college will follow the lead of Physics in the emphasis on method suggested in this monograph. Yet that is not too discouraging. We see the direction we have to travel; and if the road is long, it is high time that the journey be commenced.

FRANK M. MCMURRY,
Teachers College,
December 15, 1921.

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The influence of purpose in method of study.—It is plain that any study may be pursued from a variety of motives, and that each one of these motives may influence to a greater or less degree the method of study to be adopted. Thus one may study history in order to pass a prescribed examination, he may study it in order to appear intelligent and well informed in society, he may study it in order to apply its lessons in politics or social matters, he may study it in order to gain a livelihood by teaching it to others, or he may study it simply because he *wants to know.* Any of these motives may influence his selection of subject matter and his method of pursuing the study.

What has been said of the variety of motives which may lead to the study of history is just as true of the reasons which may be given for studying physics, and in this case, since there are more methods of study open to the student of physics than to the student of history, the method of

study will be determined by the motive much more in the case of the former than of the latter.

Thus, consider the single case of preparing for an examination in physics. The questions asked may refer merely to the statement of general laws (and these may frequently be stated either in words or in mathematical formulæ) or they may require a knowledge of how to apply these laws to a specific case. They may be qualitative, that is, they may require a descriptive answer, or they may be quantitative and require a numerical answer. They may, and often do, require an experimental demonstration. If the candidate for examination knows beforehand which kinds of questions are likely to be asked, he will do wisely to so modify his methods of study as to get the best possible preparation for the coming examination with the least amount of effort. He may prepare for one examination by the study of a single textbook, while in another case it may be necessary for him to get his preparation in a library or in a laboratory.

If the student of physics has some other aim than the mere passing of a set examination, his possible methods of study may be still more numerous. Accordingly, before a student is qualified to decide for himself upon a method of

studying physics, it is highly important for him to be informed in regard to the possible methods of studying this science which are open to him, and to have a tolerably clear comprehension of the aims which he hopes to accomplish by the study.

There are, in general, two partially distinct methods of science study which may, to some extent, be contrasted with each other. One of these is the method which is usually most encouraged in our schools and colleges, and which leads to what we know as *scholarship*. It consists largely in learning what has been known and what has been thought by the men whom the world has recognized as leaders in scientific thinking, and in trying to comprehend their thoughts and to think them over again as if they were our own. Thus, for more than a thousand years approved scholarship in science throughout Europe consisted in accepting and in comprehending more or less perfectly the teaching of Aristotle. At the present time, it consists largely in accepting and in trying to comprehend the teachings of a few recognized leaders in each department of science.

The other method of science study results from the attempt on the part of the student to acquire not only the knowledge which has been left to us by our masters of a previous age, but to cultivate

the mental habits which enabled these men to become leaders of scientific thinking in their generations.

The dependence of progress on the purpose adopted.—As a result of the greater prevalence of the training for scholarship than for scientific leadership, a few men in each generation are still compelled to do the real thinking for the whole world, while the rest of us are content to be merely their disciples. In this respect there has been but little improvement in recent times. Thus the following paragraph, which was written by Joseph Priestley in 1767, would be just as true if it were written to-day:

Priestley says:

> I think that the interests of Science have suffered by the excessive admiration and wonder, with which several first rate philosophers are considered; and that an opinion of the greater equality of mankind, in point of genius, and powers of understanding, would be of real service in the present age. It would bring more labourers into the common field; and something more, at least, would certainly be done in consequence of it. For though I by no means think that philosophical studies are at a stand, I think the progress might be quickened if studious and modest persons, instead of confining themselves to the discoveries of others, could be

brought to the idea that it was possible to make discoveries themselves.

If it is true, as Priestley believed, that there is a greater mental equality of mankind than the results of science study in the past seem to indicate, so that it is possible for "studious and modest persons" to make original discoveries for themselves, a much nobler motive for the student of science is suggested than the mere desire for scholarship. Let us, before discussing this possibility, inquire more fully into the general nature of science study, and particularly into the special character of the science of physics.

Reason for the many divisions of the field of science.—All science study results from the attempts of human beings to comprehend the universe of which they are themselves a part.

The universe is so great and so complex that all attempts at understanding it as a whole have failed; but by concentrating a great amount of thought and labor upon some small part of it at a time many things of great value have been learned.

Since by this method of acquiring knowledge each investigator must work in a very limited field, the study of the universe has been undertaken along a great number of special lines which have come to be regarded as distinct sciences.

It should be remembered, however, that these divisions have been made by man merely for convenience in applying the principle of division of labor upon which most of his other work is based. To a mind capable of a complete comprehension of the universe there would be but one science.

Advantages for study that the physical sciences enjoy.—The division and classification of scientific knowledge into separate sciences has generally been based upon certain obvious distinctions between the things about us. One of these distinctions is between living and nonliving things. The differences between these two classes of things are very great. Since we, ourselves, are living beings, our interest in living things is naturally very much greater than in nonliving, or inanimate, things. Unfortunately, the complex changes which are constantly going on in living bodies are much more difficult to comprehend than are the changes which are taking place in inanimate bodies. Besides, many of the methods which are employed in the study of inanimate bodies cannot be applied to the study of living bodies without destroying life. For these reasons, much greater progress has been made in understanding the relations between the changes in nonliving than in living bodies.

Since most of the changes which are going on in nonliving bodies are also taking place in living bodies, we may learn much about the latter by a study of the former. In fact, almost the only phenomena of living bodies for which satisfactory explanations have been found are those which are also common to nonliving bodies.

The special purpose of physics.—The science of physics has to do wholly with nonliving bodies and their relations to one another. The changes which are continually taking place in and between these bodies are very numerous, and some of them are very complex. It is the purpose of the science of physics to determine under what conditions and, if possible, why certain changes always occur. When these conditions are known, they enable us to predict or to bring about desirable changes.

Our slowness in accomplishing this purpose.—It is only within the past three hundred years that mankind has begun to learn how to predict with certainty the physical changes which will occur under specified conditions. Before that time such knowledge was usually acquired accidentally, if at all. Once every few hundred years some man was born who seemed to have a special insight into the workings of nature, and such a man always made important discoveries; but he

did not succeed in teaching other men how to make the same kinds of discoveries, and he was generally looked upon as a very superior or as a very dangerous person. Other men came to accept his merest opinions as authority in matters of science, or to look upon him as in league with the Devil. Often both opinions concerning him were held at the same time by different people.

It has thus come about that a very few men have done nearly all the important scientific thinking of the world. Most of what has passed for scientific study has resulted from the attempts of other men to find out what these few leaders have thought and, if possible, to think the same thoughts over after them.

The attempt to do even as much as this did not come early in our civilization. It has always been the tendency of human beings in the state of intellectual infancy to attribute the movements of material bodies to acts of will on the part of some being superior to themselves. It is in this way that most of the religions of the world have arisen. Accordingly, although the Greeks were apparently the earliest people to look for physical causes for natural phenomena, it has been said that the Greeks of Homer's time would not have thought of asking the cause of rain or thunder

or earthquakes, but instead, who rains, or who thunders, or who shakes the earth.

The discovery that has made physical science possible.—The fact that many of the changes which take place in nonliving bodies in our universe depend upon some kind of relation between the bodies themselves, and not upon the wills of gods or demons or other spiritual beings, is one of the greatest discoveries ever made by the human mind. Until this discovery was made all physical science was impossible; for if a given phenomenon might be caused by one god or one spiritual power at one time and by some other god or spiritual power at another time, it would be impossible to tell when this phenomenon was going to occur, or what means to take to bring it about or to prevent its occurrence. Accordingly, it was not until it was recognized that there is a part of the universe in which spiritual powers seem to play no direct part, and in which every action or change taking place is the inevitable consequence of some previous action or change, that it was possible to have a physical science.

That part of the universe in which mental or spiritual powers never intervene is known as the *physical universe*. The main purpose of the study of physical science is to acquire a comprehension

of the relations which lead to inevitable changes in the physical universe. It is upon our knowledge of these relations that our mastery of the physical universe depends.

Meaning of Natural Law.—When these invariable relations between physical phenomena have been discovered and described they are known as *natural laws.* Thus it has always been observed that a heavy body when unsupported by another body falls to the earth, or continues to fall until it is supported by another body. We can accordingly say that it is "a law of nature" that an unsupported body falls toward the earth. No one knows *why* it falls. We have learned how far it will fall in each second that it is free and how great its speed will be at the end of each second of falling. These facts, when combined into an intelligible statement, constitute what is known as *The law of falling bodies.*

It will be seen that the word "law" is not here used with its customary meaning. In the most common usage, a law means a decree or enactment by a ruler or a governing body. Such a law may be obeyed or disobeyed. Generally a penalty is prescribed for disobedience, but this penalty is not always enforced.

Another common meaning of the word law is that of a usage or custom. Thus a law of gram-

mar or spelling is merely the statement of what has come to be a customary usage. These laws have not, in general, been decreed, and when certain decrees have been announced by some organized body, as, for example, The Simplified Spelling Board, the body issuing the decree has no authority to enforce it.

A natural law differs from a decree or usage in that it is a statement of a universal, and hence inevitable, order of events. A decree may be disobeyed, regardless of consequences. The usages upon which the laws of grammar and spelling rest are very far from being universal, and are generally incapable of being so stated that there are not many exceptions to them. But a law of nature is not subject to a single exception. If a single heavy body could be lifted without the expenditure of energy or if it could remain unsupported above the earth, then would our whole present science of physics be overthrown.

Importance of our knowledge of natural laws.—Huxley has given one of the best statements of our reasons for wishing to acquire a knowledge of natural laws. He says:

> It is a very plain and elementary truth that the life, the fortune and the hap ıess of every one of us and, more or less, of

> who are connected with us, do depend upon our knowing something of the rules of a game infinitely more difficult and complicated than chess. It is a game which has been played for untold ages, every man and woman of us being one of the two players in a game of his or her own. The chess board is the world, the pieces are the phenomena of the universe, the rules of the game are what we call the laws of nature.
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> . . . . . .
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> Education is learning the rules of this mighty game. In other words, education is the instruction of the intellect in the laws of nature, under which name I include not merely things and their forces, but men and their ways; and the fashioning of the affections and the will into an earnest and loving desire to move in harmony with those laws.

Huxley seems to suggest that it is possible to be out of harmony with nature's laws, and in another place he speaks of the penalty of disobedience to natural laws; but in the strict sense a disobedience of nature's laws is an impossibility. A man who leaps from a high cliff is not punished for disobeying any law of nature; on the contrary, he obeys the law of falling bodies and takes the consequences. The so-called penalty which he pays is only an additional proof of the invariableness of natural law. The same thing

may be said of a man who contracts a contagious disease or indulges in the excessive use of alcohol or deprives himself of necessary food; he does not disobey the laws of nature—he merely exemplifies them in his own person.

Our knowledge of the laws of nature accordingly will not shield us from disobedience to them, because the very existence of a law precludes any possibility of disobedience to it; but while we cannot disobey a natural law if we would, we may, by understanding these laws, often avoid the unpleasant results of certain relations between ourselves and external things. If we thoroughly understand the rules of the game, we may predict the consequences of our moves before we make them.

Two methods of learning natural laws.—How, then, shall we learn the rules of this mighty game? Attention has already been called to two general methods which we may designate for our purpose as the method of the scholar and the method of the scientist. The former, we have seen, consists in learning from books and lectures what other men have thought about the laws of nature and in trying to think their thoughts over after them. This method leaves all the real thinking to a few men, while the rest become merely their disciples.

As has already been said, much the greater part of the physics teaching of the schools is based upon this method. We are given the opinions of Galileo and Newton and Faraday as to what constitute the rules of the game. We learn the stock arguments in favor of these opinions and we perform experiments and solve problems in order that we may have a clear understanding of the opinions which we accept; but we are given no opportunity of forming an independent opinion on the basis of our own seeing and thinking; and, what is still more to be deplored, we are given no training in the method of science study which made Galileo and Newton and Faraday our scientific authorities, and which, though used by but few men, has completely revolutionized our civilization in only three hundred years.

And yet the method of the scientist is not necessarily more difficult than the method of the scholar, for it is sometimes more difficult to understand the laborious and involved thinking of some of the leaders whom custom has selected as our guides to scholarship than it is to get, by our own efforts, a much clearer understanding of the relations which they are trying to explain. Let us, then, consider the method of the scientist.

Modern physical science compared with the old natural philosophy.—It is more than two thousand years since it was recognized by Grecian philosophers that the changes which take place in the physical universe are not merely the arbitrary acts of some god or demon, but are the inevitable consequences of physical conditions. Since this discovery was made, many of the keenest minds of the world have been devoted to the discovery of natural laws and a comprehension of their relations to each other. Down to the year 1600 these efforts were almost wholly without success. Previous to this time the human race had apparently reached its highest possible achievements in many lines of intellectual endeavor. In religion, in philosophy, in logic, in art, in music, in architecture, in literature, people still turn to the "old masters" for their models and their inspiration. In science there were no old masters.

Yet in the three hundred years that have elapsed since 1600 the whole character of our civilization has been revolutionized and most of our habits of thought have been changed by the marvelous development of physical science. It is safe to say that during any day of the year just passed greater scientific advancement was made than in the first thousand years of the Christian

Era. It would seem that a method of study which has led to such tremendous achievement in even a single line of thought would be immediately adopted by at least all the workers in that particular field, even though it could not be applied elsewhere; but the painful admission must be made that the scientific method of study, like many well-known virtues, is highly commended and seldom practiced.

Yet it must be true that if there is a peculiar method of studying physical science, the use of which has so greatly modified our civilization, the acquisition of this method of study and of thinking should be the most important aim of our education. It is when we undertake to explain this "scientific method" that the really hard part of this discussion begins. It is easy to write about textbook methods and lecture methods and laboratory methods, but it is very difficult to specify clearly what we mean by these methods. This is especially true of the so-called laboratory methods. It is difficult to find any considerable number of textbooks the authors of which would use the physical laboratory from the same motives. To a less degree, the same may be said of the different uses made of textbooks and lectures.

However, it is possible to show important

differences between the Greek methods of studying natural philosophy which prevailed down to the year 1600, and the methods of studying physics to-day. The Greeks gave a great deal of thought to Natural Philosophy, but, as we have seen, they made very little progress in the interpretation of nature. This appears to have been true partly because they made very inaccurate observations, and partly because they tried to settle questions in physical science in the same way that we now try to settle questions in what we call the political and social sciences, namely, by arguing about them. It should be remembered that the reason why a question may be argued is because the true answer to it has not been found. So it happened that while the Greeks were the best debaters and the keenest logical reasoners that the world has produced, they could make no progress in physical science.

Another reason for failure in the science study of the ancients lies in the fact that in those days men tried to discover what has been called the essence of things; that is, they tried to find some general principle from which all the phenomena of the physical universe could be logically deduced, instead of trying to find out merely the relations between these phenomena.

Perhaps a fair characterization of the common method of the natural philosophy of those days may be put in this way: the ancients tried to imagine the nature of the first cause from which the universe sprang or of the deity by whom it was created; then from their conception of this first cause or deity they drew their conclusions as to what kind of universe must have resulted or must have been created.

A similar point of view, which was held by some ancient philosophers as well as by a considerable number of more modern ones, is that the human mind is but the duplication on a smaller scale of the mind of the Creator; and that consequently we may, when undisturbed by external conditions, think over again the thoughts of the Creator, and thus arrive at a comprehension of the physical universe. Unfortunately, this method has never given an interpretation of the universe which even remotely coincided with observed relations.

Method of Roger Bacon and Leonardo da Vinci.—But even in the days when these fruitless methods of studying the universe were almost invariably adopted, an occasional man appeared who seemed to have some peculiar insight into natural phenomena. It may be worth while to inquire how these men studied physics.

One such man was Roger Bacon, a learned monk, who lived in England seven hundred years ago. Bacon wrote:

> We have three means of arriving at knowledge: authority, reason, experiment. Authority has no value if its basis is not understood; it teaches nothing, but merely calls out our assent. By reason we may distinguish a sophism from a demonstration, while we may test our conclusions by experiment.

It will be seen that Bacon suggests experiment, instead of argument, as a means of testing conclusions. However, his suggestion seems to have had no influence upon the scientific method of his time.

Three hundred years later there was living in Italy one of the famous men of history. Leonardo da Vinci was celebrated as a painter, sculptor, architect, engineer, anatomist, botanist, astronomer, poet, and musician, and he was also the greatest physicist of his time. It would seem that Da Vinci must have had superior methods of study in order to accomplish so much, no matter how great his genius. Fortunately, he has told us something of his method of studying physics. He says:

> In undertaking scientific investigations, I first plan a few experiments, because it is my

> design to base the problem on experience and then to determine why the bodies in question are constrained to act in a given manner. This is the method that one must adopt in all researches. It is true that nature begins with reason and ends in experience, but, nevertheless, we must choose the opposite way; we must, as I have already said, begin with experience and through its means strive for a recognition of the truth.[1]

Thus Da Vinci suggests that before attempting to find an explanation of a phenomenon by reasoning about it, it is necessary to observe very carefully the relations to be explained. But his suggestions were not adopted by the other scientific men of his day, and it was not until a hundred years later that another physicist appeared in Italy.

The change introduced by Gilbert and Galileo.—The year 1600 may be regarded as a turning point in the methods of scientific study. In that year Dr. William Gilbert published one of the great physical monographs of the world, in which he not only laid the foundation for the sciences of magnetism and electricity, but proposed and exemplified a new method of physical study. He says in his preface:

[1] Translated from Gerland's *Geschichte der Physik.*

> To you alone, true philosophers, ingenuous minds, who not only in books but in things themselves look for knowledge, have I dedicated these foundations of magnetic science—a new style of philosophizing. But if any see fit not to agree with the opinions here expressed and not to accept certain of my paradoxes; still let them note the great multitude of experiments and discoveries—these it is chiefly that cause all philosophy to flourish; and we have dug them up and demonstrated them with much pains and sleepless nights and great money expense.

To the English speaking world, Gilbert may be garded as the father of physical science. In s writings he constantly refers to the impor-nce of experiments.

At the present time no physicist will give any nsideration to physical interpretations which e not based upon experimental evidence, but this as not true of the philosophers of Gilbert's day, or is it true of the average man of the present ay.

The greatest scientific man of ancient times as the Greek philosopher, Aristotle. His writ-gs were the chief textbooks of European holars for more than a thousand years. His udies covered all the lines of thought of the icient world, and determined what men should

think during the middle ages. Throughout all this time approved scholarship consisted in trying to comprehend and adopt the opinions of Aristotle.

Aristotle taught, among other things, that bodies of different weight fall with different velocities, and that the speed of fall is proportional to the weight. Thus, a ten-pound ball should fall ten times as fast as a one-pound ball. Everybody accepted this opinion, and no one tested it experimentally for two thousand years. Then, when Galileo dropped two cannon balls of unequal weight from the leaning tower of Pisa and invited the multitude to see that they both reached the pavement at the same time, the "scientists" of that day believed that what they had apparently seen was a mortal error, and still accepted the teaching of Aristotle in preference to the evidence of their own senses.

The four necessary steps in the scientific method.—What has been said should be enough to make it plain that any study of physics should be based upon experiment, but it is plain that experiments may be used in various ways and for various purposes. For example, some teachers introduce them for the purpose of manual training, some use them as a means of illustrating or verifying the statements of text-

book or lecture; and many, apparently, use them as a sort of busy work, to keep their students occupied. None of these methods is what is known as the method of science. Da Vinci tells us that he used experiments before beginning the study of a problem so that he might understand clearly the phenomena which he was undertaking to interpret. Roger Bacon says "we may test our conclusions by experiment." Here are two distinct uses that may be made of experiment; namely, to enable us to understand clearly how the actions which we wish to explain actually take place, and to test our final conclusions as to the cause of the actions.

Between these two appeals to experiment there are apparently two distinct mental processes necessary. In the first place, after getting a clear understanding from our first experiments of the character of the actions which we wish to explain, we make a guess at the probable explanation; that is, we guess that a certain relation exists between the phenomenon which we are studying and some other phenomenon with which we are already acquainted. This guess is called an *hypothesis* or a generalization. The mental process concerned in its production is commonly known as *induction.*

Then we say, "If our guess is correct, certain other phenomena which we have not yet observed

must be produced by conditions which we can specify." That is, we may predict new phenomena which have never been observed. This is *logical* thinking, or the mental process commonly known as *deduction.* If our predictions have to do with the magnitude or the intensity of the expected result or with geometrical relations we may use mathematics in making our deduction. This is the only step in the scientific method in which mathematics comes into play.

The fourth step in our scientific method is the testing of our predictions by experiment. Until this step is taken our scientific process is incomplete; after it is taken we can go no further except by making other predictions and testing them by experiment. If all our predictions stand the test of experiment we may conclude that our hypothesis is actually a natural law. Later, some more advanced thinker may find a logical deduction from it which does not stand the test, and then doubt is cast upon the validity of the law, and its statement must be changed to fit the new condition.

An illustration of the difference between the scientific method and the method of argument. —To make our description of the scientific process as plain as possible, let us imagine a concrete example. Let us suppose that a traveler who has

been accustomed to modern conditions in civilized communities is walking in an uninhabited wilderness at night when suddenly he sees in front of him two long shadows of himself stretching forward nearly parallel to each other. Let us suppose his first thought to be that an automobile is approaching him from the rear. This, then, is his hypothesis.

If he uses the methods of the old Natural Philosophy, he will begin at once to argue with himself as to the probability or the improbability of an automobile's being in the wilderness. He will discuss the possibility of its traveling over the route which he has followed. He may think of the swamps and rivers which he has crossed and of the mountains which he has climbed. He may recall all that he has learned from other explorers as to the presence or absence of human habitations and roads in the surrounding country. From all these data he will probably reach a conclusion as to the probability or improbability of an automobile's being behind him, and if he is a mathematician he may state this probability as a percentage of all the possibilities which occur to him. Meantime, while following out all these lines of argument, he has stood with his back to the lights.

On the other hand, if the traveler has been

trained in the methods of modern science, while he may start with the same hypothesis, his deductions from it and his experimental tests of them may be somewhat as follows:

1. Since the shadows are cast in front of him, the lights which cast them must be behind him and must be visible. To test this deduction, he turns and looks for the lights.

2. If the lights are moving and are attached to an automobile, the engine of the machine must be running; he accordingly listens for the engine.

3. If the lights are approaching, the automobile, if such it is, must soon overtake him; and he will wait for it and determine its character.

4. If the lights are at rest, the machine, if there be one, has stopped; and he at once starts for it, meanwhile being guided by the lights. In the end, though his mental processes may be much simpler than those of the other traveler, he will know certainly whether or not the shadows are cast by the headlights of an automobile.

A noted historical example of this difference.—In order that the foregoing comparison may not seem too much like a caricature, let us consider an historical instance of the manner in which two of the world's great men attempted to explain the same concrete and fairly simple phe-

nomenon. Just two hundred years ago Newton published a treatise on *Optics*. One of the first experiments he describes consisted in making a small hole in the window shutter of a darkened room and in placing a three-cornered glass prism in the path of the beam of sunlight which entered through the hole and formed a spot of light on the opposite wall. Newton observed two important changes due to the passing of the light through the prism. In the first place, he saw that the path of the beam of light was bent where it passed through the prism, so that the spot of light on the wall appeared in a new position, and in the second place he saw that what had before been a round patch of sunlight on the wall was now a band of rainbow colors.

There seemed to be two possible hypotheses as to the cause of the colors. One was that they were already in the sunlight and had in some way been separated in passing through the prism; the other was that the light in passing through the prism took something from the glass which gave it the colors. Newton chose the former hypothesis for trial. He guessed that all the colors of the rainbow were already in the sunlight, and that while all of them were bent aside in passing through the prism, some of them were turned aside more than others. Looking at his band of

light he saw that the blue end was farthest from the position originally occupied by the spot of light on the wall and that the red end was nearest to this position. So he concluded that if the band of colors was due to the bending of beams of different colored light by his prism, it must follow that a prism would cause a greater bending of blue light than of red light. This was the logical deduction from his hypothesis. To test this deduction, he placed another glass prism in the beam of light which had passed through the first one, but placed it at right angles to the first and so that the red light would pass through it near one end and the blue light near the other end. He saw, as he had guessed, that the colored band was again turned aside in passing through the second prism, and that the blue end of it was turned aside more than the red end. His deduction was verified by experiment.

Then he argued that if light is turned aside in passing through a prism, objects seen through a prism would appear displaced from their true position, and that blue objects would appear more displaced than red objects. So he painted two squares side by side on a black screen, one blue and the other red, and looked at them through a prism. The squares appeared separated, and the

blue one seemed more displaced than the red one. Thus his second deduction was verified.

He next concluded that if the rainbow colors are caused by the separation of white light, it should be possible by combining all of them again to reproduce the original sunlight. This was a new deduction, and Newton tested it by two methods. In one method he used a second prism parallel to the first and placed it so that it would bend the beam of light which had passed through the first prism back into its original path. He saw the spot of light appear upon the wall in the same place and of the same color as if it had not passed through either prism. This experiment not only verified his deduction, but it seemed to exclude the hypothesis that light in passing through a prism took color from the prism, as it was not reasonable to assume that one prism would put color into the light and the other prism take it out.

Then Newton took seven little mirrors and mounted them so that he could place them in the band of colored light and allow a different color to fall upon each mirror. By tilting the mirrors so that they would all reflect their light to one spot he found that all the colors combined to produce ordinary sunlight. It was in this way that Newton built up his theory of color.

Ninety years after the publication of Newton's *Optics,* the German poet, Goethe, undertook to introduce another theory of colors based upon the hypothesis that the light in passing through the glass prism took up some unknown substance from the prism which combined with ordinary light to produce color. Goethe's fundamental experiment consisted in looking through a prism at a white wall, apparently expecting it to be seen in rainbow colors. When he saw it white, except for a narrow band of red on one side and of blue on the other side, he at once decided that he had overthrown Newton's theory of colors. His friends among scientific men tried to point out to him that what he had seen was exactly what might be predicted from Newton's theory, since if the wall were divided into narrow strips and the light from each strip were dispersed into the rainbow colors, these bands of colors would fall upon the neighboring strips in such a way that all the strips except those nearest to one edge would receive all the colors of ordinary light. Along this edge the red light would be least deviated, so that this edge of the wall would be bounded by a red band. Along the opposite edge of the wall all the colors would appear displaced beyond the true edge of the wall, but since blue light is displaced more than the other colors it would extend be-

yond all the other colors, and the wall would seem to be bounded on this side by a blue band.

Goethe was apparently unable to reason to this deduction. In fact, he seems to have been almost incapable of using the logical process at all. His great countryman Helmholtz, in referring to this weakness of Goethe, says:

> But this step into the region of abstract conceptions, which must necessarily be taken if we wish to penetrate to the causes of phenomena, scares the poet away.

For Goethe was a poet, and a poet, as a poet, has no use for the logical method of drawing deductions from hypotheses. The poet's generalizations are not intended as hypotheses to be tested by the methods of science.

Lowell tells us that "Poetry is not made out of the understanding," and Goethe was a poet. So he wrote a book on the theory of color, which was largely made up of repeated statements of his own beliefs and of declamation against what he calls "the disgusting Newtonian white of the natural philosophers." Helmholtz says of this attempt at the discovery of scientific truth by intuition:

> We must look upon his color theory as a forlorn hope, as a desperate attempt to rescue from the attacks of science the belief in the

> direct truth of our sensations. And this will account for the enthusiasm with which he strives to elaborate and to defend his theory, for the passionate irritability with which he attacks his opponent, for the overweening importance which he attaches to these researches in comparison with his other achievements, and for his inaccessibility to conviction or compromise.

When Goethe found that, while his theory of color was received with some favor by the intuitional philosophers of his day, it failed to convince anyone trained in the use of the scientific method, he wrote a second volume, devoted in part to a reiteration of his theory, but mostly to an indecent attack upon Newton, who was, of course, long since dead. In this attack he calls Newton's reasoning "incredibly impudent," says his theory might be "admirable for school children in a go-cart," and accuses Newton of frequently lying about his experiments, though all of them had been repeated many times by other physicists.

Now that almost a century has passed since the publication of Goethe's theory of color, Newton's interpretations of the phenomena of light and color are more firmly believed than ever, while their author is universally regarded as the greatest interpreter of nature that the world has

ever known. Goethe is still regarded as the greatest of German poets, but his venture into the field of physical science is deplored by all his admirers who know anything about it.

How skill in the different steps of the scientific method has varied.—Not all physicists have been so expert in the steps of the scientific process as Newton seems to have been; and many of them have been much more skillful in some of the steps than in others. Accordingly, it has sometimes happened that part of the process leading to an important discovery has been carried through by one man and another part of the process by another man. This was true in the case of the discovery of the barometer and the measurement of atmospheric pressure.

For hundreds of years the disciples of Aristotle had taught that the reason water can be raised by suction is because "Nature abhors a vacuum." We find the same opinion still expressed by people who tell us that the warm air in a chimney rises and the cold air rushes in to take its place. After two thousand years, the students of Galileo found that a vacuum may apparently exist in a closed tube above a column of water thirty-four feet high, and hence that nature's abhorrence of a vacuum does not extend above thirty-four feet. Torricelli, in 1643, tried the experiment with a

column of mercury, instead of water, and found that a vacuum could exist above a column of mercury only thirty inches high. Torricelli knew that a column of mercury thirty inches high weighs as much as a similar column of water thirty-four feet high. He guessed that the liquid column was in both cases held up by the pressure of the atmosphere, which must accordingly be as great as that of a layer of water thirty-four feet deep or a layer of mercury thirty inches deep. This was the hypothesis,—the second step in the scientific process.

Torricelli was apparently unable to carry through the process. He did not know how to test his hypothesis, so he merely argued about it. But Pascal saw the next step. He said that if the atmosphere were a fluid pressing down upon the earth, its pressure would be less at an elevation than at sea level. So he carried a Torricellian tube of mercury to the top of a church steeple in Paris and thought that the mercury column stood lower than when on the ground. He then wrote to his brother-in-law, who lived near a mountain, to carry the tube to the top of the mountain and observe the effect. The brother-in-law did so, and the mercury column stood three inches lower on the top of the mountain than at its base. The scientific process was completed,

and the mercurial barometer has ever since been used to measure the pressure of the atmosphere upon the earth.

The contributions of different men in the discovery of universal gravitation.—While in the case just mentioned it took the work of two men to carry the scientific process through to completion, the establishment of a discovery in science sometimes involves the work of several men, each of whom carries through but a small part of the whole process. This was true of the discovery of universal gravitation.

Three hundred and fifty years ago Tycho Brahè established the first astronomical observatory, and made a great number of measurements of the relative positions of the stars and planets at different times. He undertook to decide between the theory of Ptolemy, which made the earth the center of the universe with the sun, moon, and stars revolving around it, and a theory that had been proposed but a short time before by Copernicus, which made the sun the center of the solar system, with the earth and the other planets revolving around it.

Tycho was a skillful observer and made very accurate measurements, though the telescope had not then been invented; but he was unable to apply the scientific process to the facts which

he had discovered, and he finally decided in favor of the theory that the earth is the center of the universe. Years later he accepted as a student a young man named John Kepler, who proved to be a much abler scientific thinker than his master. Kepler, by using the measurements which Tycho had made, was able to compute with great accuracy the orbits of the planets about the sun and of the moon about the earth. He showed that all the planets move in elliptical orbits with the sun at one focus of the ellipse.

So far the work of Tycho and Kepler was descriptive, though Tycho's work involved measurements which still command the admiration of astronomers, and Kepler's work involved some of the most famous mathematical calculations of the world. Neither gave any explanation of why the planets all moved in similar orbits about the sun, or even why they moved about the sun at all. It was sixty years later before an hypothesis explaining these facts was proposed by Newton. Meanwhile, Galileo had experimented upon freely falling bodies and bodies rolling down inclined planes, and had made the discoveries which were later collected by Newton under the name of *the laws of falling bodies.* Galileo had also introduced the hypothesis of forces into mechanics, and had supposed that all bodies near the earth

are pulled toward it by a force which came to be known as the *attraction of gravitation.*

Newton, while still a very young man, undertook to calculate under what conditions one body would move in an elliptical orbit about another body placed at one focus of the ellipse. He knew that when a heavy body is fastened to one end of a string and whirled around the hand which holds the other end of the string the hand must constantly pull upon the string or the body will not move in a curved path around the hand, but will continue to move in a straight path except as it is pulled toward the earth. His computations told him that to make the body move in an elliptical path with the hand at one focus of the ellipse the pull upon the string must be greater when the weight is near the hand and less when it is farther away, and that the pull must increase just as fast as the square of the distance of the moving body decreases. This is called the *law of the inverse square of the distance.* Its calculation at that time was one of the great mathematical feats of the world.

It seemed to Newton that the moon revolving about the earth must be pulled toward the earth by a force varying in this way. Then it occurred to him that this might be the same force which pulls all falling bodies to the earth. This was his

hypothesis. He proceeded to calculate how far the moon must fall in one second toward the earth from its straight path if a body near the earth falls sixteen feet in one second and if gravitation decreases as the square of the distance between the falling body and the earth increases. The distance from the center of the earth to its surface and to the moon had both been calculated from astronomical measurements. Using these distances, Newton calculated how far the moon should fall toward the earth in one second, and he found that it did not fall as far as it should if it were pulled by gravitation. Instead of falling five and one-half hundredths of an inch, as it should from his computations, it falls only four and two-thirds hundredths of an inch in a second; hence he concluded that his deduction was not verified and, consequently, that his hypothesis was not sustained.

As a consequence, Newton did not even tell any one of his hypothesis, much less attempt to defend it by argument; but accepted the test of his deduction. He says that he "laid aside at that time any further thought of the matter." So he went on with his investigations in optics, his invention of the reflecting telescope and the sextant, and his work on the differential calculus that has

been such a powerful tool in the hands of mathematicians since that time.

Twenty years later a new measurement of the curvature of the earth was made by Pickard, which gave the radius of the earth as about four thousand miles, instead of 3436 miles, the distance used by Newton in calculating how much the pull of gravitation should be at the distance of the moon. Newton had found that the moon falls toward the earth one thirty-six hundredth as far in a second as does a body at the surface of the earth, and the new measurement of the earth's radius made it one-sixtieth of the moon's distance. Since the square of sixty is thirty-six hundred, the pull of the earth at the distance of the moon should be one thirty-six hundredth as great as at its surface, and Newton's deduction was finally verified.

Newton seemed at that stage to have proved that the same gravitation which makes the apple fall from the tree extends as far as the moon, and falls off with the inverse square of the distance. But if gravitation may extend from the earth to the moon, why not to the sun? The earth moves about the sun in the same kind of curved path in which the moon moves about the earth. There should accordingly be a force which

varies with the inverse square law between the earth and the sun, and Newton saw the whole solar system moving according to one general law.

But this was, again, a new hypothesis, or rather an extension of his original hypothesis beyond the limits for which it had been verified. So Newton inquired if there might not be some effect of the moon's gravitation on the earth which would enable him to test whether the sun produced a similar effect. There was. The tides were known to follow the apparent movement of the moon around the earth, and Newton was able to explain these by the difference in intensity of the moon's gravitation on the side of the earth nearest it and the side farthest from it. If the effect of the sun's gravitation reached the earth, it should also produce tides. Newton was able to point out these tides and show that they were of the proper magnitude, and hence that his hypothesis as to the extension of gravitation throughout the solar system was justified. Such was the scientific method of Newton.

And such is the method by which scientific knowledge has always been acquired. It is the *scientific method.* It can be used in its entirety better in the study of physics than in the study of any other science. That is why physics has developed so much more rapidly than any

her science. It is also the reason why one can quire facility in the use of the *scientific method* tter in studying physics than in studying any her subject.

Importance of the scientific habit of thinking. Is it important to acquire facility in the scien- ic habit of thinking? Let Professor John ewey answer this question. He says:

> One of the only two articles that remain in my creed of life is that the future of our civilization depends upon the widening spread and the deepening hold of the scientific habit of mind; and that the problem of problems in our education is therefore how to discover and how to mature and make effective this scientific habit. Mankind so far has been ruled by things and by words, not by thought, for till the last few moments of history humanity has not been in possession of the conditions of secure and effective thinking.

Again, Professor Dewey says of the scientific ethod:

> It represents the only method of thinking that has proved truthful in any subject—that is what we mean when we call it scientific. It is not a peculiar development of thinking for highly specialized ends; it *is* thinking so far as thought has become conscious of its

proper ends and of the equipment indispensable for success in their pursuits.

If it is true that the mental process which we have called the method of science is "the only method of thinking that has proved truthful in any subject," it would seem that a training in this method should surpass in importance any other kind of mental training. It is true that the method cannot be used in its entirety in any other field of knowledge; but it is likewise true that in any field where it cannot be applied, we cannot hope to attain to the same degree of certainty that we may in physical science.

Significance of the scientific method in other fields than physics.—This, at least, it may do for us in other fields—it may teach us that opinions formed upon other matters are just as truly hypotheses until logically made deductions from them have been verified as they are in physical science. It is here that argument has its proper place, which is, principally, to assist us in the formation of a clearer understanding of what may be involved in our hypothesis. Argument is commonly used to convert another to our hypothesis, rather than to test the hypothesis. An argument usually consists in a series of logical deductions from the hypothesis under consideration, but if such deductions are incapable of ex-

perimental test they can be of value only when they lead to some relation which is known to exist, or when they lead to an absurdity. If the latter case should happen in a single instance the hypothesis must be abandoned or reconstructed so that it will avoid the absurdity.

The mental attitude necessary.—Thus we may learn to approach the investigation of other subjects in much the same attitude of mind as we would begin the investigation of a question in physical science. This mental attitude has been very clearly described by Faraday in his lecture on "The Education of the Judgment." Faraday says:

> I believe that in the pursuit of physical science, the imagination should be taught to present the subject investigated in all possible, and even in impossible views; to search for analogies of likeness and (if I may say so) of opposition—inverse or contrasted analogies; to present the fundamental idea in every form, proportion, and condition; to clothe it with suppositions and probabilities, that all cases may pass in review, and be touched, if needful, by the Ithuriel spear of experiment. But all this must be *under government,* and the result must not be given to society until the judgment, educated by the process itself, has been exercised upon it. Let us construct our hypotheses for an hour,

> or a day, or for years; they are of the utmost value in the elimination of truth which is evolved more freely from error than from confusion; but above all things let us not cease to be aware of the temptation they offer, or, because they gradually become familiar to us, accept them as established.

This is a description of a kind of argument which may be applied in other fields as well as in physical science, and it suggests the value of discussion with others; for it is seldom that a single person is able to present all the possible, not to say the impossible, views of a very simple question. The danger of discussion is that we may have a much greater predilection for the points of view which we present ourselves than for equally significant points of view when presented by another, and the love for truth may easily be lost in the pleasure of successful combat or the struggle to maintain an hypothesis merely because it is one's own. Above all, it must not be forgotten that *the establishment of truth is a mental, not a vocal, process.*

The danger from prejudice.—The tendency to a warping of the judgment through prejudice or through the expectation of a particular result is one of the most difficult things to overcome, even when our expectation is in no way influenced

by our desires. It is much more so when the matter under consideration has a personal bearing upon ourselves or our friends, or when it is concerned with a belief which has been inculcated by previous education. To overcome this danger the investigator in physical science usually tries to work out the experimental tests of his deductions without knowing until they are finished what their bearing upon his hypothesis will be. Thus, a chemist may balance his sample to be analyzed by another body of unknown weight, so that he may remain ignorant of the proportions which he should obtain if his hypothesis is to be verified. Not until his analysis is complete will he weigh his counterpoise and compute the quantities which his hypothesis leads him to predict.

Faraday, in the lecture already referred to, calls especial attention to the danger of having our judgment warped by prejudice, and we have already seen a deplorable example of this in the case of the poet Goethe. Faraday says:

> The *inclination* we exhibit, in respect to any report or opinion that harmonizes with our preconceived notions, can only be compared in degree with the *incredulity* we entertain towards everything that opposes them; and these opposite and apparently incompatible, or at least inconsistent, conditions

are accepted simultaneously in the most extraordinary manner. At one moment a departure from the laws of nature is admitted without the pretence of a careful examination of the proof; and at the next, the whole force of these laws, acting undeviatingly through all time, is denied, because the testimony they give is disliked.

I will simply express my strong belief, that that point of self-education which consists in teaching the mind to resist its desires and inclinations, until they are proved to be right, is the most important of all, not only in things of natural philosophy, but in every department of daily life.

Suggestions for overcoming prejudice.—It would appear from the above considerations that something more than a knowledge of the scientific method of procedure is necessary to one who would become an independent investigator of phenomena,—that the mental traits which are generally included under the term character are quite as important in scientific work as in other fields of endeavor. It would seem to follow that a complete discussion of how to study should at least advise one as to how the mind can be taught "to resist its desires and inclinations until they are proved to be right."

This is more difficult than to describe the scientific method of thinking. The question is, How

may one form a habit of developing hypotheses and of deducing their logical consequences without being influenced by the bearing which his conclusions may have upon himself or upon other people? In the opinion of the present writer, this *habit* may be acquired most easily in a field of investigation where the personal applications are not appreciable. Thus, in the beginning, one is perfectly indifferent as to whether a suspended magnet sets north and south or east and west, or whether a free body falls sixteen feet or twenty feet in one second. His only concern is to determine the truth. If he continues to work with this sole end in view, the determination of truth will gradually become a more and more important motive, and it may finally become so important as to be stronger than his prejudices and desires.

Thus, the habit of seeking only the truth, combined with the fact that the scientific investigator who misrepresents the results of an investigation immediately receives the contempt of all men of science throughout the world, becomes a powerful corrective of prejudice and helps the investigator to be always "upon honor" with himself.

In this connection, Professor Tyndall has said of the study of physics:

> It requires patient industry, and an humble and conscientious acceptance of what

> nature reveals. The first condition of success is an honest receptivity and a willingness to abandon all preconceived notions, however cherished, if they be found to contradict the truth. And if a man be not capable of this self-renunciation—this loyal surrender of himself to Nature—he lacks, in my opinion, the first mark of a true philosopher. Thus the earnest prosecutor of science, who does not work with the idea of producing a sensation in the world, who loves the truth better than the transitory blaze of to-day's fame, who comes to his task with a single eye, finds in that task an indirect means of the highest moral culture. And although the virtue of the act depends upon its privacy, this sacrifice of self, this upright determination to accept the truth, no matter how it may present itself—even at the hands of a scientific foe, if necessary—carries with it its own reward. When prejudice is put under foot, and the stains of personal bias have been washed away—when a man consents to lay aside his vanity and to become Nature's organ—his elevation is the instant consequence of his humility.

The kind of problem suitable for training in scientific method.—Thus far these pages have been devoted largely to an attempted description of the methods of the scientist as distinct from the methods of the scholar. It was stated in the

beginning that there are two partially distinct methods which may, to some extent, be contrasted with each other. It is true, however, that it would be very difficult if not impossible to follow the scientific method to the exclusion of the other, except as a mere matter of training. It would not be difficult to select for purposes of training a list of scientific problems which a student could be taught to solve by the scientific method without knowing what had, or had not, been done by others. So long as the purpose is training only, it is a matter of no consequence whether the answer of the question which is being put to nature is already known to others or not. However, a teacher in putting such questions should know whether they are capable of being answered through the knowledge and skill already acquired by his pupil, and he can know this only if the question has already been answered, and if he is familiar with the process by which the answer has been obtained. Thus, for purposes of early training, a teacher is virtually compelled to confine himself to problems the answers to which he already knows; but it is necessary, if the student is to be trained in the scientific method of interrogating nature, that he shall not know beforehand the answer which he is seeking.

To the learner, any scientific question to which

he does not know the answer may serve as a problem upon which to try his skill, but the danger is that the beginner will select a problem so difficult that no one has been able to solve it. In interrogating nature it is necessary to go very slowly, taking a single step at a time, and it is very difficult to break up the complex problems which seem to us nearest and most important into the simple problems of which they are built up. The most difficult task of a leader of investigation is to analyze the complex relations which exist everywhere in nature into simple relations which lend themselves to scientific investigation. Usually there are not more than two or three men in the world working in physical science who are capable of making this analysis, and such men inevitably become world leaders in investigation. A man who belongs to this class must have both scientific insight and scholarship. De Morgan says:

> New knowledge, when to any purpose, must come by contemplation of old knowledge, in every matter which concerns thought; mechanical contrivance sometimes, not very often, escapes this rule. All the men who are now called discoverers in every matter ruled by thought, have been men versed in the minds of their predecessors,

and learned in what had been before them. There is not one exception.

The need of studying the methods of former scientists.—It should be noted that De Morgan lays stress upon the fact that a successful investigator should be "versed in the minds" of his predecessors,—not merely acquainted with the knowledge which they have possessed. This is equivalent to saying what has already been said in these pages, that the way to learn the successful method in science is to study the methods of the men who have been the most successful investigators. This knowledge can only be acquired by reading the original descriptions of the investigations as given by their authors; it cannot be gained by reading second-hand descriptions compiled by other writers. To one who wishes to learn how to investigate physical phenomena, Tyndall's *Sound* or his *Heat: A Mode of Motion* is worth many textbooks on physics; and Faraday's *Experimental Researches in Electricity* is of more value than all the libraries of scientific knowledge which have ever been compiled.

Results of the scientific method.—We have already seen that until about three hundred years ago the human race had made little more progress in its conquest of the physical universe than

it had in other lines of human endeavor. Since that time we have made comparatively little progress in the acquisition of knowledge concerning "men and their ways," while each decade now carries us farther than the preceding century in our comprehension of physical laws.

Why have we not also made progress in our comprehension of things of the spirit? Within the possible span of a single life the physicist has taught the little whirligig of Hiero to do the work of millions of men, and thus to banish human slavery from the earth; he has released the spirit that was imprisoned in the amber and made it his mighty servant and messenger of light; he has compelled the faithless wings of Icarus to bear him at will over mountains or sea; but the student of Literature, of Music, of Art, of Philosophy, of Morality, of man's relations to his Maker, must still go for his inspiration to the old masters. When only a few years ago a popular magazine took a vote of the leading thinkers of the world on the question "What are the seven wonders of the modern world?" six of the seven selected were achievements of modern physics, and the seventh a recent achievement of an allied science.

And we have seen why this is so. In the year 1600, Dr. Gilbert announced to the world a new

method of discovering the laws of the physical universe, and proved the accuracy of his method by discovering more of the laws of magnetism and of electricity than had all his predecessors since the beginning of time. That same year Giordano Bruno was burned at the stake in the streets of Rome for daring to defy the authority of the church in matters of the intellect; and the young professor, Galilei Galileo, was risking a similar fate in dropping iron balls from the tower of Pisa to see if they would really fall with a speed proportional to their weight, and in daring to recognize through his home-made telescope the spots on the sun, though ecclesiastical authorities had warned him that the sun must have no spots. For the first time in the history of our race men had begun to test their conclusions by experiment and to cross-question Nature experimentally to compel her to yield her secrets. It is this method of Gilbert and Galileo which has come to be called the scientific method, and it is due to the employment of this method by a few individuals in each generation that our era has come to be known as "The Age of Science."

Responsibility of teachers for centering attention on scientific method.—It would seem that it is only in the possession of this one method of learning "the rules of the game" that the hu-

man mind is more competent than it was in the days of Aristotle or Socrates. And when we remember that this method of science which has, within the memory of living man, so transformed our earth has been acquired by only a few individuals among the many millions now living, we recognize the tremendous responsibility of the teachers who are chosen to guide beginners in the method of science. For the beginner, unless he be one of the world's great geniuses, must be guided by one who has learned to find his way about. No one travels in an unknown land by the aid of guide books,—he must depend rather upon his knowledge of physiography, his training in woodcraft and his ability to supply his own necessities from the natural resources of the country. Until he has acquired these necessary accomplishments he must rely upon a guide who has acquired them. It will depend upon his use of the knowledge which he acquires from this guide whether he will ever be able to find his way about without assistance. And the teacher to whom is intrusted the training of the young men and young women who aspire to scientific attainment has not faithfully discharged his responsibility until he has given them a mastery of the only method of investigation which has ever been suc-

cessfully employed by human beings to compel Nature to surrender her secrets for the benefit of mankind.

Even the most enlightened members of our race still know very little about the physical universe. They are pioneers who have only recently landed upon the shores of an unknown world. They have blazed a few trails into the surrounding wilderness, and have ascended a few conspicuous mountain peaks. To some of these outlooks they have built easy roads, and have invited others to look out with them over the unknown country. They know that this country contains many wonderful mountains and fertile valleys which have never yet been trodden by the foot of man. It is the ambition of the pioneers of science first to blaze trails and then to find practical routes for roads into these "delectable mountains." It is the duty of the teacher of science to give the young men and young women who come to him a sufficient training so that they may at least be able to step aside from the beaten trails to gather the flowers and fruits which grow so profusely along them. Many will never venture far from the trail, but once in a long time will come a student with the courage and instincts of the pioneer, who wishes to go

beyond the landmarks of other men, and him the true teacher welcomes, not as a pupil, but as a companion and brother.

It is these stalwart ones, who play their game of life single handed and away from their fellows, to whom the human race owes all it has achieved in the conquest of the physical universe. They are little known or heeded by the great unthinking mass of their fellows, but no greater happiness can come to the true teacher of science than to stand as a guide and companion to a few of these chosen ones.